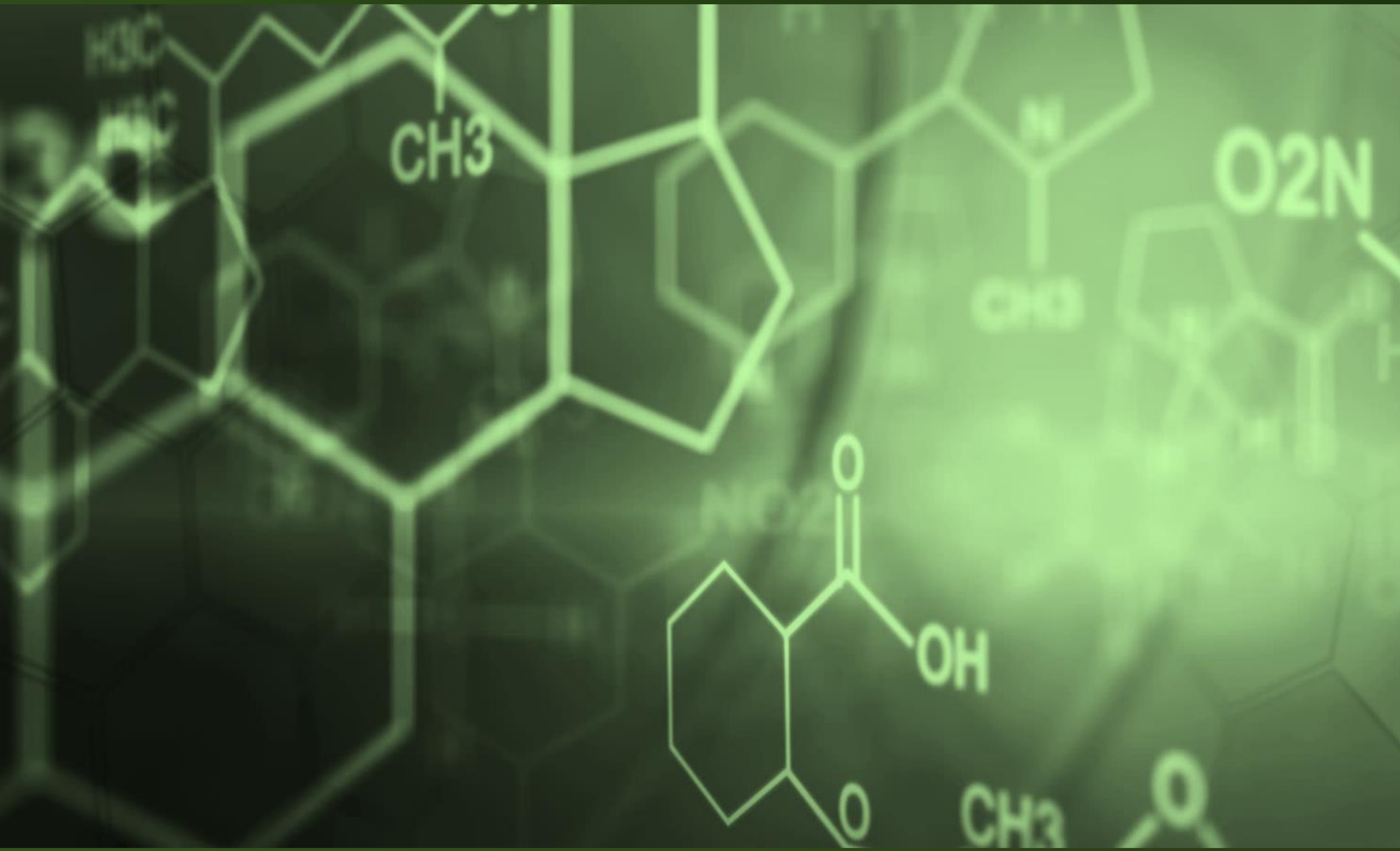

A Technical Overview of the EnviroLeach® Gold Recovery Process

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1. Overview

The hydrometallurgical extraction of gold from ores, concentrates, tailings and electronic waste in both a cost effective and environmentally safe manner offers an interesting challenge. Gold, as one of the most valuable of the precious metals, is produced by both conventional mining methods and more recently, from end-of-life electronic waste, known today as ‘urban-mining’. Both of these methods require a safe and effective alternative to their current extractive technologies.

Conventional gold mining operations rely heavily on cyanide leaching as the predominant method for recovering gold from ores and concentrates. Cyanide has been the leach reagent of choice in gold mining because of its high gold recoveries, robustness and relatively low cost. As a result, over 76% of all gold extracted worldwide is produced by hydrometallurgical extraction with the use of cyanide.[i]

Gold extraction from electronic waste is typically based on either pyro metallurgical (smelters) methods or hydrometallurgical based hot acid digestion methods. Both industry sectors are being challenged by reduced grades, higher production costs, more complex ores and materials and increasingly more stringent environmental guidelines.

Within both sectors, the use and subsequent disposal of cyanide and strong acids, present significant safety and environmental challenges. As a result, these safety, environmental and associated permitting issues have been a significant driver for the industry to evaluate alternative lixiviants.

FIGURE 1 – ATOMIC ABSORPTION SPECTROSCOPY ANALYSIS OF SOLUTIONS

These alternative lixiviants have to offer comparable leach kinetics, and be environmentally friendly and cost effective. Some of the experimental alternative lixiviants include; thiosulfate, thiocyanate, ammonia, bromine, chlorine, bisulfides, Iodine, and thiourea. Some of these chemicals offer comparable leach kinetics under certain conditions, but for a variety of reasons, none are reported to be an effective alternative to cyanide.

Although new processes are being proposed on a regular basis, there have in fact been no dramatic changes in the metallurgical techniques for gold extraction since the introduction of the cyanide process (cyanide leaching or cyanidation) by McArthur and Forrester in 1887.

Recently, **EnviroLeach Technologies Inc.** announced the development of a unique, effective and environmentally safe alternative to cyanide. The **EnviroLeach Process**, has been found to be eco-friendly, safe and provided faster leach kinetics than cyanide in many instances. Also, as a result of its reusable nature, it can be economical in comparison with both cyanide and acid digestion methods.

The EnviroLeach process is similar to the approach used for cyanide leaching. It involves the dissolution of the valuable metals into the aqueous solution followed by extraction using conventional methods such as electrowinning, carbon absorption or precipitation. It is simple and does not require complex process circuits. It operates at near neutral pH levels and at a wide range of temperatures. Some of the operational benefits include:

- Faster & more effective leach kinetics
- Environmentally friendly & safe
- Broad applicability spectrum
- Near neutral pH conditions
- Operates at ambient temperature
- No off-gas or detox controls required
- Reusability of solution
- Simplified recovery of metals from solution

A background of the general approach and test results from a number of ores and concentrates via this system are presented herein. The chemistry of the system is not presented due to the fact that process and chemistry are currently under patent application.

> *The Summary of the test results indicate that the EnviroLeach reagent routinely exceeds the performance of cyanide for ores and concentrates and gold can be effectively recovered using carbon absorption or conventional electrowinning.*

2. Background

The oxidizing lixiviant consists of a base formula of non-toxic dry ingredients which are mixed with water. The oxidant is uniquely generated and regenerated for re-use electrochemically. While the primary formula was found to leach gold, a number of leach enhancing agents have been identified that improve the gold leach kinetics as well as the stability of the gold that has leached into solution.

These leach modifying additives are a unique and key component in the effectiveness of this process.

EnviroLeach has reported to Met-Solve that over 1,000 individual tests have been completed by their in-house staff. Additional Independent testing and analysis was performed by Met-Solve Laboratories Inc. in Langley, BC, which are reported herein.

The tests involved the preparation, and subsequent leaching of numerous different ores, gravity concentrates, flotation concentrates, tailings and electronic waste products in the EnviroLeach solution.

Following the leach cycle, analysis of the solution was performed by Atomic Absorption spectroscopy, ICP mass spectrometer and the analysis of the leach residue by acid digestion, ICP MS and fire assay.

The EnviroLeach product performed better on both kinetics and total amount of precious metal recovered metrics. The metals are very stable in solution and there are no preliminary indications to a maximum solubility level.

Using the proprietary formula and process, EnviroLeach extracts precious metals from the host material into solution in a safe, environmentally friendly and sustainable fashion.

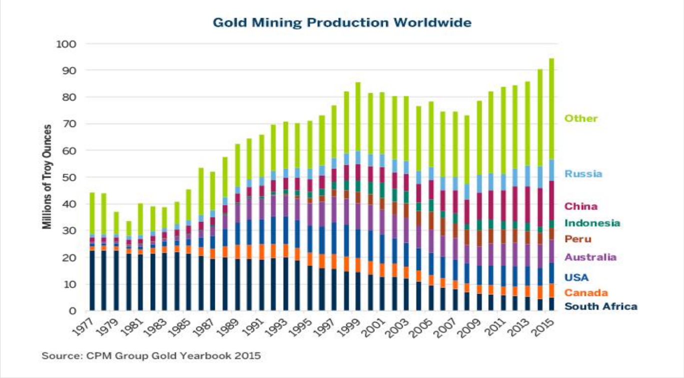
The company’s primary target industry sectors are the Mining Sector for the treatment of ores, concentrates, and tailings and the E-Waste Management Sector for the treatment of electronic waste streams.

The writers believed it important to include basic industry profiles of both sectors in this paper in an effort to provide some quantitative data to support the unique positioning and broad applicability spectrum of this product.

3. Target Markets

3.1 The Mining Sector

Mining is one of the world's most important economic sectors. Globally, the gold mining industry directly contributed around US$ 80 bn to the global economy in 2013. If the indirect economic effect of the industry’s expenditure on supplementary goods and services is included, this amount increases to US$ 171.6 bn.



Source: CPM Group Gold Yearbook 2015

Figure 2 - Worldwide Gold Production - CPM Group 2015 – CME Group [ii]

In 2005, world gold production was estimated to be 2,470 metric tons. Since then, world gold production has steadily increased and in 2015 it was estimated to be at 3,000 metric tons with an estimated overall value of over US$120 bn.[iii]

The mining sector continues to face challenges due to increasing costs, lower commodity prices, more stringent environmental policies, lack of investment capital and lower exploration spending.

In order meet these challenges, investment will focus on innovation through the use of automation and technologies to improve operational efficiencies, streamline production and minimize environmental impact at existing assets.

Securing a social license to operate is a serious issue for the gold mining industry. The value of a company’s assets below ground can only be realized if the social, political ecological and environmental conditions above ground allow the resource to be permitted and eventually proceed to production. [iv]

In 2015, the global community of the United Nations has developed a new set of Sustainable Development Goals (SDGs) that include an unprecedented focus on the role of businesses in socioeconomic and environmental impact of the host communities. The importance of minimizing the environmental impact of mining and the reduction of ecological risk is of utmost importance.

FIGURE 3 - AGITATED CYANIDE PLANT

A recent study by SME indicates that over 76% of gold is produced using cyanide extraction[v]. The gold mining sector uses approximately 66,000 tons of sodium cyanide worldwide[vi]. Both the use and disposal of cyanide present significant safety and environmental risks.

Cyanide and cyanide gas are both toxic and care has to be taken during ore processing to avoid exposure for workers. Solutions containing cyanide have to be carefully monitored and managed to prevent the formation of deadly cyanide gas. In addition, there are significant costs associated with destruction of cyanide in the tailings streams and final disposal.

While cyanide in the environment and open air can break down into other compounds relatively quickly, it can still persist at quantities that are above regulatory levels in the environment.

The various species of cyanide that remain in tails streams from gold plants are potentially toxic, and on some operations the waste streams are processed through a detoxification process prior to tails deposition. This reduces the concentrations of these cyanide compounds, but does not completely eliminate them from the stream.

Internationally, several counties, like the Czech Republic, Greece, Turkey, Germany, Hungary, Costa Rica, Argentina, Ecuador, and some states of the United States (e.g. Montana) have banned cyanide leach technology in gold and silver mining. In Korea, the cyanide leaching operations have stopped because of high labour costs and environmental issues.[vii]

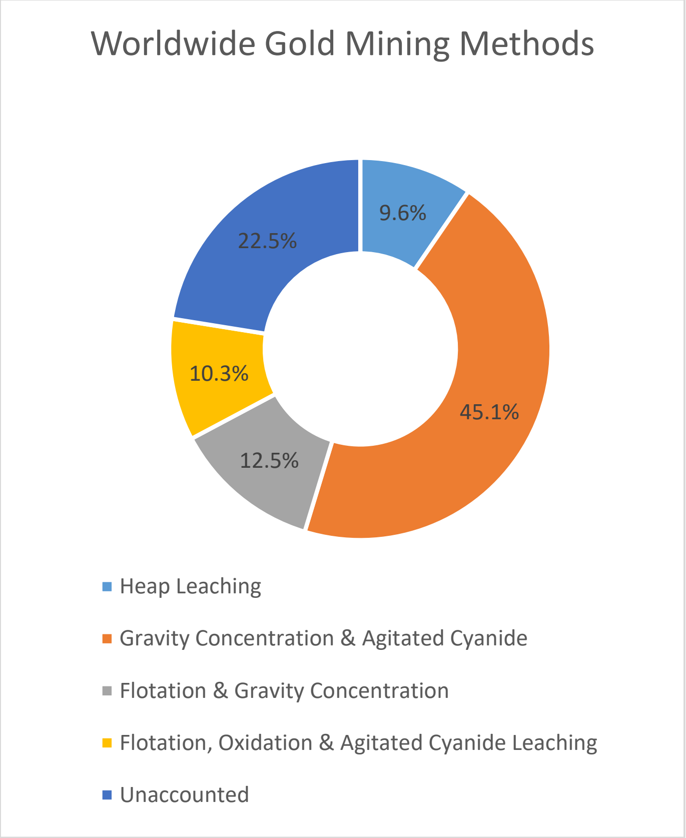


FIGURE 4 - GOLD PRODUCTION BY EXTRACTION METHODS

The EnviroLeach product is ideally suited for the leaching of gold in agitated or vat leach type processes or intensive leach methods. These include the treatment of whole ores, gravity concentrates and flotation concentrates. These reported segments of the market, not including heap leach processing, account for over 76% of all gold produced worldwide.

3.2. The E-Waste Sector

According to a report offered by US-based Market Research Store, the global e-waste management market was valued at US$17.0bn in 2015. In terms of volume, it stood at 86.40 million tons in 2015. As reported, North America accounted for approximately 33.0 % of the total revenue generated in 2015. [viii]

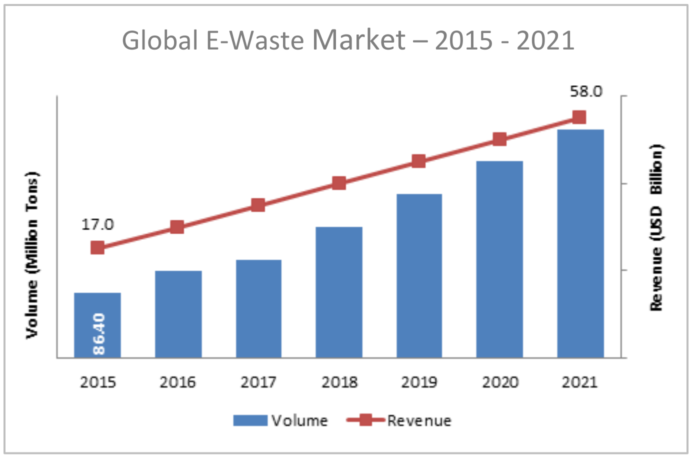


FIGURE 5 - GLOBAL E-WASTE MARKET - 2015-2021 - MARKET RESEARCH STORE

The sector is expected to grow to US$49.4bn by 2020, registering a CAGR of 23.5% during the forecast period 2015 - 2020. It is one of the fastest growing waste streams in emerging as well as developed regions. The reduced life spans of electrical, electronic and consumer electronic devices are generating large quantities of E-Waste, which is growing rapidly every year.

According to the United Nations initiative to estimate E-Waste production, the world produced approximately 50 million tons of E-Waste in 2012, on an average 15 lbs per person across the globe. In 2012, the UN also stated that, UK produced, 1.3 million tons of electronic waste. China generated 11.1 million tons of E-Waste, which was followed by United States that accounted for 10 million tons in 2012.[ix]

Electronic waste - including mobile phones, TVs and computers – is thought to contain as much as 7% of all the world's gold. [x] However the “minerology” in scrap products is much different than in conventional ores in a gold mine.

FIGURE 6 - HIGH GRADE CIRCUIT BOARDS – SOURCE: BOLIDEN SUSTAINABILITY REPORT

Up to 60 different elements are closely interlinked in complex assembly’s sub-assemblies, and this currently requires specialised metallurgical processes with extensive off-gas treatment to recover gold and a wide variety of other metals cost effectively and in an environmentally friendly fashion. [xi]

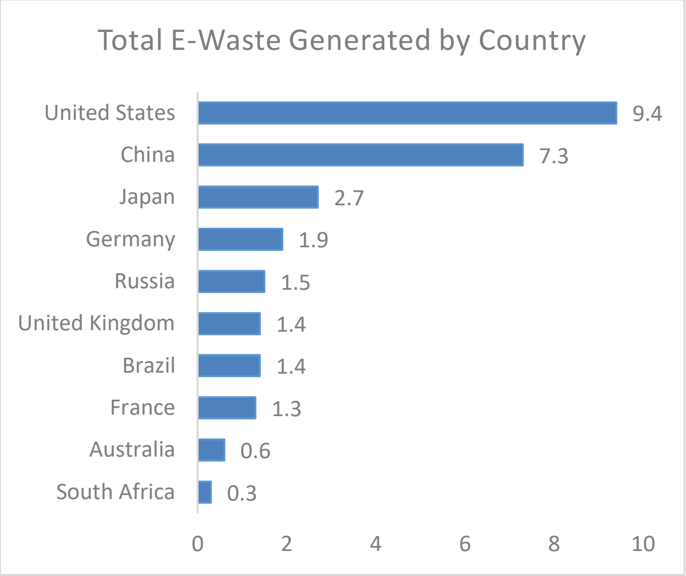


FIGURE 7 - WORLDWIDE E- WASTE GENERATED BY COUNTRY- [xii]

The consumer growth rate of electronic devices continues to increase day by day and their in-built features continue to become ‘smarter and quicker’ each year, which has led to a substantial net increase in gold demand over recent years. [xiii] Other drivers in the E-Waste sector growth can be attributed to the following:

- Decreasing life span of electronic devices
- Rate of Obsolescence
- Increased adoption of technologies
- High cost of recycling
- Limited eco-friendly recovery processes

Due to the declining lifespan of devices, this source of electronic scrap offers not only an important recycling potential for the secondary supply of gold into the market but also a growing one. With gold concentrations reaching 300-350 g/t for mobile phone handsets and 200-250 g/t for computer circuit boards, this e-scrap is an ‘urban mine’ that is significantly richer in gold than the sources of the primary ores today.[xiv]

E-waste recycling will play a significant role in the coming decade and impact industries globally, thereby boosting economy through e-waste management. Moreover, the logistics to “excavate” and “haul” the scrap products to the concentrator and further to the smelter are much more challenging than in the primary supply chain. Currently, only a small portion of old products is collected and directed into state-of-the art recycling chains. Significant improvements are needed here to fully utilise this secondary metal resource.

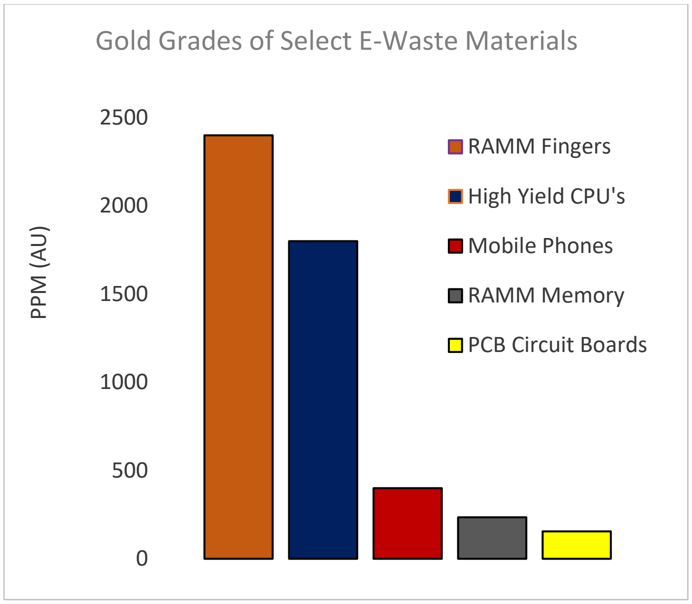


Figure 8 – Typical Gold Grades in Select E-Waste [xv]

Gold accounts for more than half of the revenue from e-waste materials. [xvi] The number of gold mines available is limited and they are often in particular geographic locations where there have been political tensions. Economic uncertainty can influence the availability of gold. The demand for gold in electronics continues to increase.

4. Leach Test Work

Test work was carried out to compare the response of the EnviroLeach process to cyanide leaching. Most of the test work was carried out using the bottle roll method that is employed extensively for cyanide leach test work however a few tests were done using a stirred reactor and lab scale agitators.

The test were done under ambient temperature and atmospheric conditions. Three different leach enhancing agents were tested and are labeled as LM-A, LM-B and LM-C. The tests were done with varying levels of lixiviant concentration and leach enhancing additives.

Figure 9 – Bottle Roll Tests

Figure 10 – Ore Samples on Mixers

4.1 Ore Sample – Ore #1

Results comparing cyanide leaching to the EnviroLeach system for a gold ore grading 3.5 g/t presented graphically in Figure 11. (EnviroLeach shown in Charts as X-Leach)

The kinetics of gold extraction using the EnviroLeach formula are significantly faster than cyanide and in all cases, the ultimate gold extraction significantly higher.

The test with the high concentration of EnviroLeach with leach enhancer LM-B achieved 80% gold recovery after 6 hours compared to 77% after 24 hours with cyanide leaching.

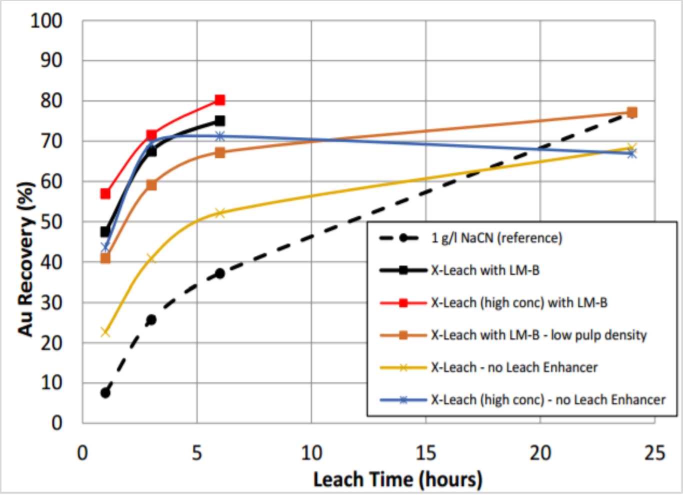


Figure 11 – Gold recovery vs Cyanide for ORE #1

The importance of adding a leach enhancer (in this case LM-B) is evident in the results in Figure 11. Without the enhancer, gold recovery may peak then drop during the remainder of the test period, probably due to some re-precipitation mechanism that is not fully understood at this time.

4.2 Ore Sample – Ore #2

The second sample, Ore #2, grading 20 g/t, was tested under varying conditions using leach enhancing agent LM-B. The results are plotted in Figure 12. Gold recoveries under standard EnviroLeach conditions are similar to those using cyanide however, by increasing the oxidant concentration, gold recovery was increased by over 10% at significantly faster leach kinetics.

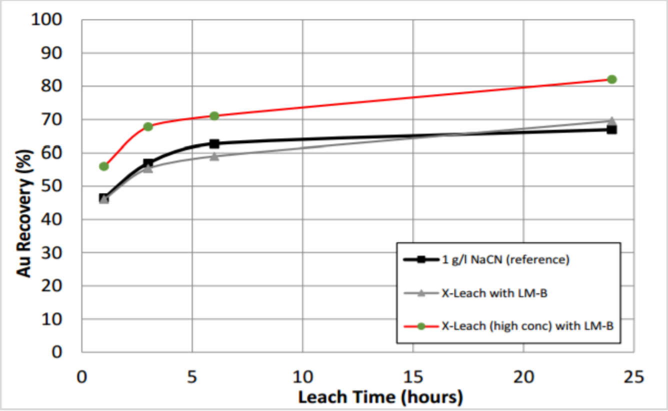


FIGURE 12 - GOLD RECOVERY VS CYANIDE FOR ORE #2

4.3 Concentrate Sample – Con #1

Concentrate samples generated from centrifugal gravity units, such as Falcon and Knelson Concentrators, have been identified as an important potential application for the EnviroLeach technology.

These concentrates typically contain coarse gold and gangue and often require more intense leaching conditions to achieve gold recovery in reasonable leach times.

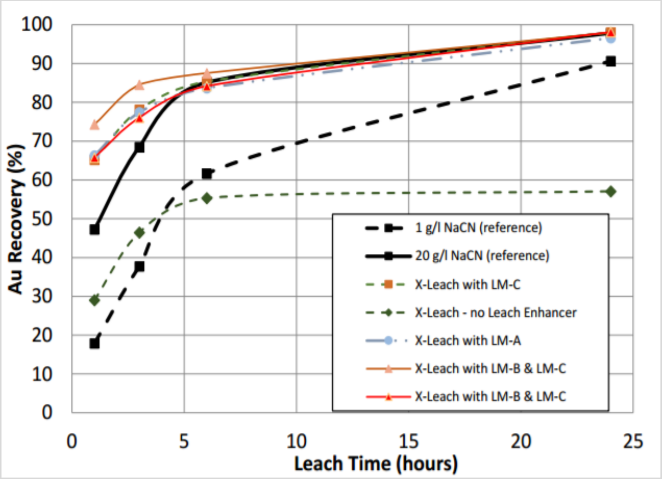


FIGURE 13 – GOLD RECOVERY VS CYANIDE FOR CON - 1

A low sulfide concentrate was tested under varying conditions and leach enhancers as shown in Figure 13. The standard leach protocol using 1 g/t cyanide resulted in 90.6% gold recovery into solution. Raising the cyanide concentration to 20 g/l increased gold recovery to 97.9%, reflecting the need for a more aggressive or intensive leach environment for this type of high grade, coarse, gravity concentrate.

The EnviroLeach system with no leach enhancing reagent resulted in a gold recovery of only 57.1%. However, by adding leach enhancing agents (LM-C or a combination of LM-C & LM-B) gold recoveries increased to 98.1% which is comparable to the high concentration cyanide results, and in general provided equivalent or faster kinetics.

4.4 Concentrate Sample – Con #2

A high-sulfide concentrate was tested under various conditions with various combinations of leach enhancers. The results are presented in Figure 14. For this sample; cyanide provided faster kinetics and slightly higher overall recoveries compared to the EnviroLeach system.

Further optimization of the leach chemistry is required to determine if improvements in the performance of the EnviroLeach system can be achieved. Current short-term research is underway to gain a further understanding of the mechanisms of the EnviroLeach chemistry for these types of applications.

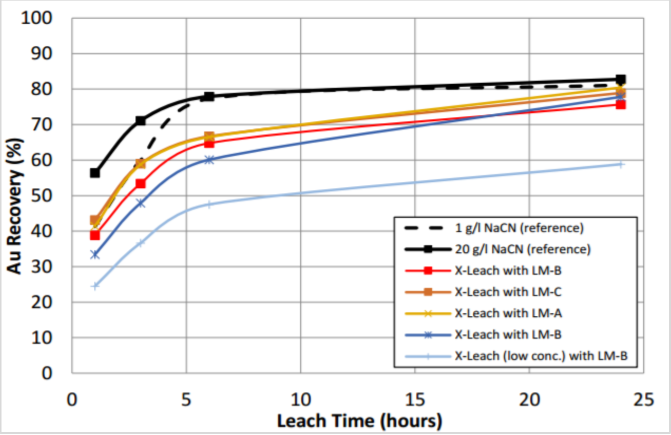


FIGURE 14– GOLD RECOVERY VS CYANIDE FOR CON #2

4.5 Gold recovery from solution via electrowinning

A single test was completed to quantify gold recovery from solution with conventional electrowinning (EW) using the Electrometals EMEW® cell. The results plotted in Figure 15 show that gold in EnviroLeach solutions can be rapidly electrowon to very low tenors.

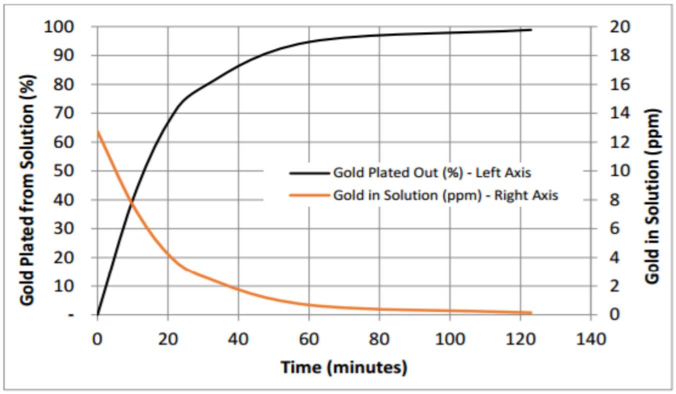


FIGURE 15 – ELECTROWINNING OF GOLD FROM ENVIROLEACH

This further supports the objective of replacing cyanide with the EnviroLeach chemistry in that auxiliary processes, e.g. carbon-in-leach and conventional electrowinning, are immediately applicable to the EnviroLeach system, and that the EnviroLeach chemistry may be a viable replacement for cyanide at the commercial and/or industrial level.

FIGURE 16 - EXTRACTION OF GOLD FROM SOLUTION USING A LAB SCALE EMEW® CELL

5. Process Overview

The overall process for leaching and recovery of gold is presented in Figure 17 below.

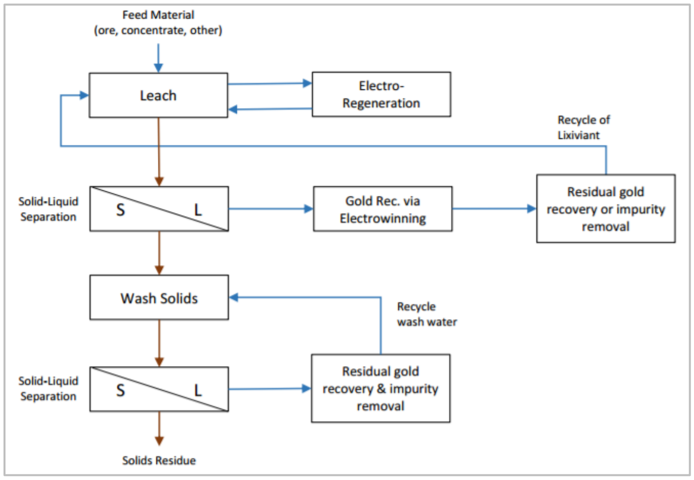


FIGURE 17 – ENVIROLEACH PROCESS FLOW SHEET

The overall EnviroLeach process consists of the following key steps:

1. Leaching of the feed material
    a. Feed materials identified for leaching include gravity concentrates, flotation concentrates, whole ore and electronic scrap.
    b. Leach performance does not appear to be sensitive to pulp density.
    c. The leach process is in a closed circuit with an electrochemical regeneration system to regenerate the oxidant as needed.
    d. Some solution clarification may be required prior to regeneration of lixiviant.
    e. Gold may or may not be recovered on the cathode in the electro-regeneration unit.
    f. Some solution clarification may be required prior to electro-regeneration.

2. Conventional solid-liquid separation can be used to separate the PLS (Pregnant Leach Solution) from the solid residue.

3. Gold recovery from the PLS can be achieved via conventional electrowinning.

4. Removal of co-leached impurities may be required prior to re-use and recycle of the barren lixiviant back to leaching.

5. Secondary washing of the residual solids may be required to recover residual gold in solution and associated lixiviant chemicals entrained in the solid residue from the primary solid-liquid separation stage.

6. Wash solutions can be subject to additional gold recovery or used as make-up solution in the process. Similarly, the wash solution may be subject to further impurity removal prior to recycle to the wash circuit or leach circuit.

7. As additional test work is completed a further understanding of the overall solution balance will be developed prior to taking the process to full commercial development.

8. Report Authors – Analytical lab

Met-Solve Laboratories Inc.

MET-SOLVE LABORATORIES INC. is a full service metallurgical laboratory and provides operations such as, but not limited to, the following:

- Mineral beneficiation
- Sample Preparation including crushing, grinding, dewatering and scrubbing
- Classification – screening, de-sliming, cycloning
- Gravity Concentration – centrifugal concentrators, shaking tables, spirals
- Dense Medium Separation (DMS
- Flotation
- Hydrometallurgy

Met-Solve was founded on the principle that effective process development in extractive metallurgy requires more than just a set of lab tests. It begins with an understanding of the client's overall objectives followed by working to achieve them through the integration of modern testing methodologies and technologies.

With decades of experience in mineral processing and plant reviews, Met-Solve Laboratories offers a convenient solution for operations looking to optimize their plant, increase production and/or improve recoveries. Working with the plant operators and metallurgists, we organize a sampling program of the plant and conduct a wide variety of metallurgical tests on site or at our facilities located in Langley, BC.

Met-Solve has access to a network of engineers, mineralogists and project managers to ensure that all analysis, reporting, and recommendations will be of the utmost benefit to the client. Producing mines looking to increase margins by improving plant performance will benefit from using a consulting laboratory in place of installing an on-site metallurgical facility.

8. Report Authors - Individuals

Ishwinder Grewal, B.A.Sc., M.A.Sc., P.Eng., President
Ish has over 20 years' experience in the metallurgical and mineral processing industry, focused on research and development, mineral processing and hydrometallurgical separation and metal recovery systems. He obtained his bachelor's degree in Metals and Materials Engineering from The University of British Columbia (UBC). He went on to complete his master's degree, also at UBC, specializing in hydrometallurgy with a focus on high pressure and temperature leaching systems. After completing his graduate studies, he spent 4 years conducting hydrometallurgical research at UBC, in areas such as gold-cyanide and base metal leaching systems, high temperature/pressure leaching processes and various ion-exchange and solvent extraction methods. He then joined Placer Dome as a Research Metallurgist at their research and testing laboratory in Vancouver. In recent years, he devoted his expertise and knowledge in the metallurgical industry as an independent consultant, laying the foundation in 2006 for the start-up of Met-Solve Laboratories Inc.

Alex Lum, P.Eng., Metallurgical Engineer
Alex has 17 years' experience working in process development, research and conducting detailed laboratory test work. His most recent tenure in the industry was with Aker Kvaerner Chemetics at their Technology Centre in Burnaby, British Columbia. He has extensive background in chemical systems, especially in the area of electrochemical processing and corrosions analysis. His experience in electrochemical field includes laboratory testing, analytical and site support for sodium chlorate, chloralkali and chlorine dioxide plants in Indonesia, Australia and Canada. Alex graduated from the University of British Columbia (UBC) in Metals and Materials Engineering where he conducted his undergraduate work in Hydrometallurgy, studying the kinetics of solvent extraction of zinc from perchlorate solution using Di 2-ethyl-hexyl phosphoric acid (D2EHPA) under the supervision of Dr. David Dreisinger.

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